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# IMPACT OF RADIOACTIVE CONTAMINATION OF SOILS ON THE DIVERSITY OF MICROPOPULATION AND THE TRANSFORMATION OF ORGANIC SUBSTANCES

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**Aim.** To study the impact of different levels of radioactive contamination on the organic matter decomposition and the population development of microbial decomposers of organic matter in soil. **Methods.** Gamma-spectrometry for the determination of the relative activity of  $^{137}\text{Cs}$  and beta-spectrometry for the determination of the relative activity of  $^{90}\text{Sr}$  in order to choose the contamination range for the studies; Tea Bag Index (TBI), the standard globally accepted method to determine the rate of organic matter decomposition; gas chromatography – to determine the impact of the investigated factors on the formation of the biomass of microorganisms by means of the  $\text{CO}_2$  production potential; classic microbiological methods, using elective media to estimate the population densities of culturable microbial decomposers. **Results.** The studies (from April to September 2021) comprised two soils with different radioactive contamination ranges: Range No. 1 in Narodychi district of Zhytomyr region (the village Khrystynivka, 3 sampling points) in the unconditional (obligatory) resettlement zone after the catastrophe in the Chernobyl nuclear power plant (ChNPP) (it has an absorbed dose rate gradient, evaluated for soil microorganisms, from 0.2  $\mu\text{Gy/h}$  (at sampling point Narodychi-1: 51,24076°N, 29,21497°E) to 1.57  $\mu\text{Gy/h}$  (at sampling point Narodychi-3: 51,23815°N, 29,22245°E)), located on the agricultural field, abandoned after the catastrophe and Range No. 2, located on the afforested area, directly bordering the territory of the so-called Red Forest in the ChNPP exclusion zone (4 sampling points – the first three points – natural ecosystems, and 4th – pyrogenically transformed territory after fires in 2020) with the absorbed dose rate gradient from 3.7  $\mu\text{Gy/h}$  (at sampling point ChEZ-1: 51,38595°N, 30,03035°E) to 84.0  $\mu\text{Gy/h}$  (at sampling point ChEZ-4: 51,38231°N, 30,03298°E). The dependence of the studied indicators on the gradient of soil contamination with radionuclides was demonstrated and these are the conditions that the difference is more than 400 times in the values of the ionizing radiation absorbed dose rates formed by radionuclides in soil. In Range No. 1 (on the fallow land), with the increase in the dose rate up from 0.2 to 1.57  $\mu\text{Gy/h}$ , there was statistically significant increase of mineralization coefficient and percentage of reduced weight of rooibos tea between the least and most contaminated sampling points), stimulation of the development of micromycetes (by 1.2–2.3 times), cellulose-decomposing bacteria (by 7.1–7.9 times), and ammonifying bacteria (by 1.8–6.3 times) due to a significant increasing the number of colony-forming units in points with higher radionuclide contamination and an increase of microbial biomass in soil more than twofold between the least and most contaminated sampling point of Range No. 1. In Range No. 2, in the ChNPP exclusion zone, characterized by low parameters of sod-podzolic soil fertility (humus content from  $1.2 \pm 0.2$  to  $0.9 \pm 0.1$  %, exchangeable acidity from  $4.0 \pm 0.1$  to  $5.0 \pm 0.7$ ), the number of micromycetes and ammonifying bacteria in soil was one-two orders below the indices of Range No. 1. Micromycetes dominated in the groups of cellulose-decomposing microorganisms. There was statistically significant increase of mineralization coefficient and percentage of reduced weight of rooibos tea with increasing of radionuclide contamination level for the first three plots: ChEZ-1, ChEZ-2 and ChEZ-3 of Range No. 2. **Conclusions.** In the fallow land of the unconditional (obligatory) resettlement zone, the increase of the radiation absorbed dose rate in soil by one order from 0.2 to 1.57  $\mu\text{Gy/h}$  does not inhibit the development of microorganisms in soil, rather it stimulates their activity and increases their numbers. On poor sod-podzolic soils in the exclusion zone of the Chernobyl nuclear power plant, the preponderance of development of micromycetes over bacterial cellulolytics is noticeable. The radioactive contamination affected the development of soil microorganisms and the biological processes in soils not only in the first years after the Chernobyl catastrophe, which has been described

in the literature, but has had its influence for rather a long time (for over thirty years after the accident). Among the microorganisms of a saccharolytic mode of organic plant residuals decomposition, the micromycetes dominate.

**Key words:** the Chernobyl NPP, radioactive contamination, microorganisms-decomposers of organic matter, vegetative material decomposition.

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## INTRODUCTION

The elimination of the consequences of extensive radiation accidents has provided mankind with rich experience of putting into practice both practical and fundamental knowledge about the radiation safety of society and environmental objects. Since the global scientific community got involved in solving the Chernobyl problems, in rather a short period of time (3–5 years), the radiation situation in the entire territory of Ukraine was taken under control (Baryakhtar et al, 1996), including the agricultural production under acceptable levels of its radionuclide contamination. After the accident on Fukushima-1 NPP (IAEA, 2015), these processes were handled much more efficiently due to objective reasons, including the experience of Chernobyl (Steinhauser et al, 2013). The prevalence of practical needs in scientific research has narrowed down the volumes of conducting fundamental works in studying the impact of the radiation factor on biological objects in the impact zone of radiation accidents, thus, the achievements in this direction are much more modest (Prister et al, 2013). The study of the impact of penetrating radiation on some biota representatives, including soil microbiota, even in the ChNPP exclusion zone, is very limited to date (Gudkov, 2020). There is an ongoing scientific debate about the consequences of the extended impact of ionizing radiation rates on biodiversity (Beresford et al, 2020).

It is noteworthy that the radiation situation around the faulted radiation objects is unique from the standpoint of using the territories as a scientific range to conduct various scientific studies, including the conditions for the existence of soil microbial populations and to evaluate their activity depending on the levels of radionuclide contamination (RC) of soil. However, researches up till now were mainly directed at determining the potential of microorganisms in terms of their impact on the transformation of radioactive substances. For instance, considerable attention was paid to microorganisms isolated from uranium mines and other natural environments with increased content of radionuclides (Avery et al, 1999); there is a detailed description of different ways of physical and chemical transforma-

tion of cesium and uranium compounds (including biosorption, biotransformation, biomineralization, and intracellular accumulation) under the impact of microorganisms (Lloyd et al, 2005). It was also shown that there is a possibility of both an increase and a decrease in the uptake of radionuclides into plants when some bacterial strains are used for pre-sowing inoculation of seeds of cultivated plants (Illienko et al, 2019; Illienko et al, 2020). A positive effect of seed inoculation is not limited to rhizosphere bacteria. For instance, Japanese researchers (Haidary et al, 2017) described that inoculation of soybean seeds with arbuscular fungi promoted the accumulation of  $^{137}\text{Cs}$  by mycelium in the roots, which limited its relocation to other parts of the plant.

Studies, directed at determining the specificities of soil microbiota functioning under the effect of penetrating radiation, however, are scarce. Among them, noteworthy are publications on micromycetes of the scientific school of N.M. Zhdanova (Zhdanova et al, 1991; Zhdanova et al, 1991; Tugay et al, 2005). These authors studied the effect of higher doses of ionizing radiation on the metabolism of micromycetes and changes in their populations. They demonstrated the increase in the synthesis of melanin, radiotropism, and stimulation of micromycete development induced by ionizing radiation. Melanin-containing genera of fungi occupied a dominant position in the soil micromycete complexes of places with the highest levels of radionuclide contamination and were recognized by the authors as more radioresistant.

Romanovska et al (1996) conducted investigations in the 10-km area of the ChNPP zone in 1993–1995 and demonstrated a decrease in the number and diversity of soil prokaryotes compared to the control soils. In particular, the number of cellulose-decomposing, nitrifying, and sulfate-reducing bacteria decreased by one to three orders.

An attempt of a comprehensive evaluation of the total microbial activity in soil, contaminated with radionuclides due to the ChNPP catastrophe, was made by Kalashnikova et al (1996) The authors suggested that the processes of formation of  $^{137}\text{Cs}$  forms available to plants are determined mainly by the microbiologi-

cal activity in the soil, while  $^{90}\text{Sr}$  is determined by the physicochemical conditions of the medium. Kravchenko et al (1999) noted a considerable decrease in the number of soil bacteria in the soil, contaminated with radionuclides, which positively correlated with a reduced distance from the ChNPP.

While studying the microbiota state in soils, contaminated with radionuclides, it is relevant to have an experimental determination of the changes in the state of populations of cellulose-decomposing soil microorganisms as one of the main microbiota groups, ensuring the initial links of trophic biological chains, including the formation of soil fertility (Singh et al, 2017).

Taking the above into consideration, our study was aimed at investigating the specificities of development and functional activity of microbiota, responsible for decomposition of organic plant residuals in soils of Ukrainian Polissia, contaminated with radionuclides.

## MATERIALS AND METHODS

Prior to the study, we searched plots/fields with experimental ranges which would meet the following requirements: a) a considerable gradient by the index of soil contamination with radionuclides in a relatively small territory; b) maximal homogeneity in terms of soil-climatic conditions and landscape.

During screening (October–November 2020), several land plots were selected in the territories which according to the Law of Ukraine belongs to unconditional (obligatory) resettlement zone and the ChNPP exclusion zone. On these selected plots, we conducted an additional sampling of soil to determine the current level of RC, and measurements of the  $\gamma$ -radiation ambient equivalent dose rate (RKS-01 “STORA-TU”, Ukraine, “ECOTEST”, <http://ecotest.ua/>).

Composite soil samples were collected using the envelope method. Soil samplings were collected using a special cylindrical sampler ( $d = 37$  mm) digging to the 10-cm layer depth in five points per one sampling point with 1–2 m distance between those: four in the corners and one in the center of a sampling point. The samples were subsequently combined to form a composite. The soil composites were dried (at  $105$  °C), sifted through sieve (cells  $d = 1$  mm), carefully homogenized and  $1000$   $\text{cm}^3$  volume of soil was taken for  $^{137}\text{Cs}$  (14 soil composites were analyzed),  $100$   $\text{cm}^3$  volume – for  $^{90}\text{Sr}$  activity concentration measurements (7 soil composites were analyzed).

The  $^{137}\text{Cs}$  activity concentration was determined in laboratory conditions using gamma-spectrometry (SEG-

001 “AKP-S”-63, Ukraine, “Atomkompleksprylad”);  $^{90}\text{Sr}$  was isolated from the samples using radiochemical methods (ISO, 2009; Pavlotskaya, 1997), and then its activity was measured by beta-spectrometry (SEB-01-70, Ukraine, “Atomkompleksprylad”).

The absorbed dose rate for soil microorganisms in the sampling points was evaluated according to the results of measurements of the  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  radionuclides activity concentration in soil (Spirin and Pimenov, 2011). The exposure dose rate from  $\gamma$ - and  $\beta$ -radiation in the 10-cm-deep soil layer was determined considering the coefficients of dose transformation for  $^{137}\text{Cs}$  by  $\gamma$ -radiation –  $4.82\text{E-}03$  ( $\mu\text{Gy/day}$ )/ $\text{Bq/kg}_{\text{soil}}$ , by  $\beta$ -radiation –  $2.47\text{E-}03$  ( $\mu\text{Gy/day}$ )/ $\text{Bq/kg}_{\text{soil}}$ . The coefficients of dose transformation for  $^{90}\text{Sr}+^{90}\text{Y}$  regarding  $\beta$ -radiation were  $1.56\text{E-}02$  ( $\mu\text{Gy/day}$ )/ $\text{Bq/kg}_{\text{soil}}$  (Spirin and Pimenov, 2011).

To determine the rate of organic matter decomposition by microbiota, we used the Tea Bag Index (TBI) method, which is a standard for global practice (Keuskamp et al, 2013). The essence of the method lies in using two kinds of TM Lipton tea bags – green tea (EAN8714100770542) and rooibos tea (EAN8722700188438), as standardized vegetative material. In this case, the obtained results may be compared with similar data, obtained for various ecosystems in different regions in the world.

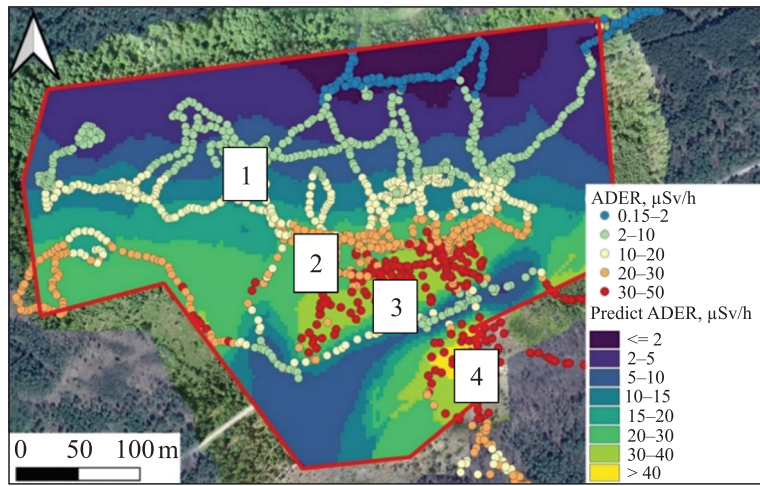
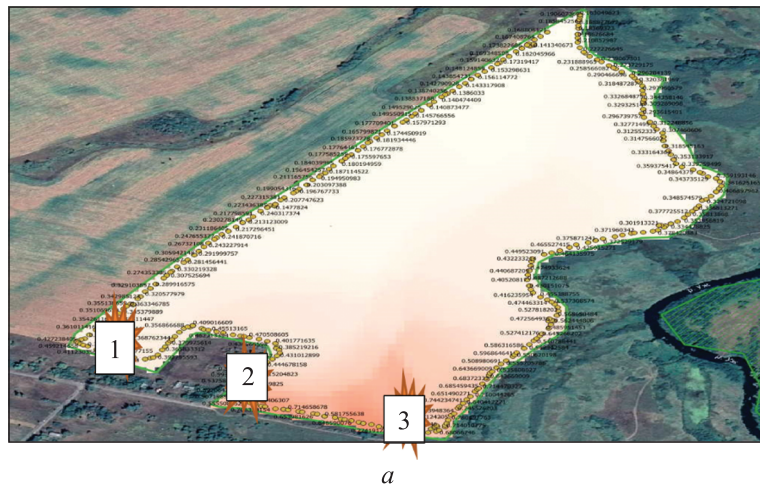
The tea bags were weighed on electronic scales, marked, placed into soil at the depth of 8 cm, and left for 90 days. After this exposure, the tea bags were removed, cleaned from soil residues, dried in the cabinet drier at  $70$  °C for 48 h and weighed again. The data obtained were used to evaluate the parameters of the so-called TBI-index: decomposition coefficient ( $k$ ) and stabilization coefficient ( $S$ ). The coefficients were determined using formulas of Keuskamp et al, 2013. Totally we used 84 bags of green tea and 84 bags of rooibos tea.

Two ranges of contamination were chosen for further research. Range No. 1 is located on the border with the exclusion zone (Narodychi district of Zhytomyr region – a zone of obligatory (unconditional) resettlement). Within Range No. 1, three points of vegetative material layouts (tea) and sod-podzolic soil samples were chosen; they had different levels of RC (Narodychi 1, Narodychi 2, Narodychi 3 – see **Table 1**). Range No. 2 (which has four points of the vegetative substrate layouts and soil sampling, ChEZ 1, ChEZ 2, ChEZ 3, and ChEZ 4, respectively – see Table 1) was selected in the ChNPP exclusion zone (Chornobyl district of

**Table 1.** The coordinates and the values of radiologic indices in the layouts of vegetative substrate and soil sampling

Points of sampling	Coordinates of sampling location		Ambient equivalent dose rate (ADER), $\mu\text{Sv/h}$	$^{137}\text{Cs}$ soil activity concentration, kBq/kg	$^{90}\text{Sr}$ soil activity concentration, kBq/kg	Absorbed dose rate, $\mu\text{Gy/h}$
	North	East				
<i>Range No. 1*</i>						
Narodychi-1	51,24076°	29,21497°	0.127 ± 0.010	0.60 ± 0.04	0.03 ± 0.01	0.20
Narodychi-2	51,24029°	29,22043°	0.411 ± 0.030	2.90 ± 0.08	0.20 ± 0.01	1.00
Narodychi-3	51,23815°	29,22245°	0.737 ± 0.040	4.60 ± 0.10	0.30 ± 0.01	1.57
<i>Range No. 2**</i>						
ChEZ-1	51,38595°	30,03035°	1.700 ± 0.040	10.40 ± 0.20	0.80 ± 0.10	3.7
ChEZ-2	51,38446°	30,02888°	10.200 ± 0.300	62.40 ± 0.60	5.00 ± 0.40	22.2
ChEZ-3	51,38358°	30,03060°	25.500 ± 0.500	149.30 ± 1.40	25.00 ± 0.30	61.6
ChEZ-4	51,38231°	30,03298°	34.800 ± 0.500	203.80 ± 4.10	34.00 ± 0.30	84.0

Note. \* – the range is located in agricultural fields, abandoned in the 1990s (the village of Khrystynivka, Narodychi district, Zhytomyr region). \*\* – ChNPP exclusion zone (the first three plots: ChEZ-1, ChEZ-2, and ChEZ-3 – natural ecosystems, plot 4 – was transformed pyrogenically after a fire in 2020 (the village of Chystohalivka, Chornobyl district, Kyiv region).



Experimental ranges on a map: *a* – Range No. 1, sampling points Narodychi 1, Narodychi 2, Narodychi 3; *b* – Range No. 2, sampling points ChEZ 1, ChEZ 2, ChEZ 3, ChEZ 4

Kyiv region). Attention was focused on the area of the so-called «Red Forest», because it is the most radionuclide contaminated territory of the exclusion zone. The territory of the «Red Forest» is not quite suitable for carrying out the tasks set by the research, as at the time, it had a powerful human impact (collecting and burying the trees which perished in the first weeks after the catastrophe, taking off and burying the upper soil layer, covering the surface with sand, etc.). Therefore, we selected an area, bordering the Red Forest territory which might meet the set criteria. Certainly, the places, selected in Range No. 2, were characterized by a much higher level of radionuclide contamination compared to those in Range No. 1, see Table 1 and **Figure**. In each point, the layout of vegetative material (tea bags) was done in six repeats for each kind of tea (green and rooibos according to Keuskamp et al, 2013).

The places of sampling in Range No. 1 are characterized by rather a considerable gradient of RC (Table 1) and their soil characteristics are close in terms of agrochemical indices. The points of Range No. 2 also have close agrochemical soil parameters within the range (**Table 2**) and sod-podzolic soil type. The homogeneity of climate conditions separately for Range No. 1 and Range No. 2 is ensured by the geographic proximity of the experimental plot locations (maximum of several hundred meters between some plots, see Figure). The radionuclides soil activity concentration in the points selected for research differs many times (more than 7 times for <sup>137</sup>Cs activity concentration and 10 times for <sup>90</sup>Sr activity concentration on Range No. 1, more than 19 times for <sup>137</sup>Cs activity concentration and more than 42 times for <sup>90</sup>Sr activity concentration on Range No. 2), and it is logical to assume that the exposure absorbed dose of soil microbiota will also differ many

times (7.85 times on Range No. 1 and 22.7 times on Range No. 2).

Table 1 shows that for Range No. 1, the index of γ-radiation ambient equivalent dose rate ranged from  $0.127 \pm 0.01$  to  $0.737 \pm 0.04$  μSv/h. For Range No. 2 in the ChNPP exclusion zone, this index ranged from  $1.7 \pm 0.04$  to  $34.8 \pm 0.5$  μSv/h. In terms of this parameter, the difference for the entire experiment was over 270 times.

There were also considerable differences in the level of soil contamination with radioactive isotopes. For Range No. 1, the values of the <sup>137</sup>Cs activity concentration in soil were within the range of  $0.6 \pm 0.04$  to  $4.6 \pm 0.1$  kBq/kg. The same index for Range No. 2 in the ChNPP exclusion zone was in the range of  $10.4 \pm 0.2$  to  $203.8 \pm 4.1$  kBq/kg. The difference between the values of <sup>137</sup>Cs activity concentration in point Narodychi-1 and ChEZ-4 was over 300 times.

The contamination with <sup>90</sup>Sr was also considerably different within each separate range (Table 1). The sod-podzolic soil of Range No. 1 had the <sup>90</sup>Sr activity concentration  $0.03 \pm 0.004$  kBq/kg in the point of Narodychi-1 and  $0.3 \pm 0.01$  kBq/kg in the point Narodychi-3. The soil of Range No. 2 at ChEZ-1 –  $0.8 \pm 0.1$  kBq/kg and at point ChEZ-4 –  $34.0 \pm 0.3$  kBq/kg, respectively. The difference between the <sup>90</sup>Sr activity concentration values for points Narodychi-1 and ChEZ-4 was over 1,000 times. Microbiota of the investigated soils, developing under this level of RC, will have been exposed to considerable ionizing radiation doses which was confirmed with estimations of absorbed dose rate (Table 1). According to our evaluations, the absorbed dose rate (due to the ionizing radiation of <sup>137</sup>Cs and <sup>90</sup>Sr), received by microorganisms in Narodychi-1 and

**Table 2.** The characteristics of the main agrochemical indicators of soils in the layouts of the vegetative substrate and soil sampling. (given in the “Methods” section)

Points of sampling	Content of humus, %	Content of mobile phosphates, mg/kg of soil	Content of exchangeable potassium, mg/kg of soil	Exchangeable acidity (pH<)
<i>Range No. 1</i>				
Narodychi-1	$2.3 \pm 0.1$	$428 \pm 90$	$164 \pm 18$	$6.2 \pm 0.1$
Narodychi-2	$2.6 \pm 0.2$	$434 \pm 20$	$161 \pm 20$	$6.2 \pm 0$
Narodychi-3	$2.7 \pm 0.1$	$444 \pm 59$	$196 \pm 78$	$6.3 \pm 0.5$
<i>Range No. 2</i>				
ChEZ-1	$1.2 \pm 0.2$	$76 \pm 11$	$12 \pm 2$	$4.0 \pm 0$
ChEZ-2	$1.1 \pm 0.2$	$54 \pm 8$	$15 \pm 3$	$4.1 \pm 0.2$
ChEZ-3	$1.1 \pm 0.2$	$64 \pm 9$	$12 \pm 3$	$4.2 \pm 0.2$
ChEZ-4	$0.9 \pm 0.1$	$50 \pm 8$	$17 \pm 3$	$5.0 \pm 0.7$

ChEZ-4, was 0.2 and 84 µGy/h, respectively, which differed more than 420 times. This gradient in radiological characteristics of soil should allow for the evaluation of the consequences of the impact of the radiologic situation on the population structure and development and activity of microorganisms.

Soil samples for microbiological research were selected close to the layouts of tea bags in April, July, and September of 2021. The number of microorganisms of some ecologic-trophic groups was studied: representatives of saccharolytic (micromycetes, cellulose-decomposing bacteria) and peptolytic (ammonifying microorganisms) modes of vegetative decomposition of plant residuals. Determination the total number of micromycetes was done using Chapek’s medium, cellulose-decomposing bacteria – on a liquid mineral medium with cellulose (strips of filter paper) as the only carbon source, ammonifiers –on meat-peptone agar (Gerhardt, 1981; Volkogon et al, 2010).

The total microbial biomass in the soil was determined gas chromatographically based on the maximum production of CO<sub>2</sub> (substrate-induced respiration method (SIRM). The essence of the method lies in evaluating the amount of active microbial biomass under the introduction of glucose solution into the investigated

soil sample to achieve the maximal release of CO<sub>2</sub> and subsequent evaluations using empirical coefficients to convert the volume of carbon dioxide into the microbial biomass (Anderson, and Domsch, 1973; Bailey et al, 2008).

The gas samples were analyzed using the gas chromatograph Tsvet-500 M (Dzerzhinsk, Russia) with the electron capture detector (bridge current 130 mA). (Anderson, and Domsch, 1973; Bailey et al, 2008).

The statistical processing of experimental data was conducted using disperse analysis (ANOVA) and software packages of Microsoft Office Excel 2010 and STATISTICA 10. While determining the number of cellulose-decomposing bacteria with the liquid medium of Imshenetsky and Solntseva, we used most probable number method (Ferguson and Ihrle, 2018).

### RESULTS

The results of the study of cellulose-decomposing activity of a sod podzolic soil microbiota on Range No. 1 are presented in **Table 3**. The estimated coefficients S and k for tea samples of the first layout, placed into soil for 90 days, under the lowest activity of radioactive isotopes in soil are 0.442 ± 0.056 and 0.0073 ± 0.0018, under the medium activity – 0.407 ±

**Table 3.** The change in the Tea Bag Index (TBI index) as indicator of decomposition of organic matter, depending on the level of contamination with radionuclides in soil plots of Range No. 1 (exposure in April-June 2021)

Indices	Points of sampling		
	Narodychi-1	Narodychi-2	Narodychi-3
Total absorbed dose rate ( <sup>137</sup> Cs + <sup>90</sup> Sr), µGy/h	0.20	1.00	1.57
Stabilization coefficient (S)	0.442 ± 0.056 <sup>a</sup>	0.407 ± 0.034 <sup>a</sup>	0.428 ± 0.044 <sup>a</sup>
Mineralization coefficient (k)	0.0073 ± 0.0018 <sup>a</sup>	0.0259 ± 0.0156 <sup>b</sup>	0.0166 ± 0.0022 <sup>a,b</sup>
Reduced weight of green tea, %	47.0 ± 4.7 <sup>a</sup>	49.9 ± 2.8 <sup>a</sup>	48.1 ± 0.3 <sup>a</sup>
Reduced weight of rooibos tea, %	14.4 ± 2.7 <sup>a</sup>	27.7 ± 4.8 <sup>b</sup>	24.1 ± 0.3 <sup>b</sup>

Note. Letters a, b, c, and d indicate statistically significance at p ≤ 0.05. Each coefficient should be compared separately.

**Table 4.** The change in the TBI index depending on the level of contamination with radionuclides on Range No. 2 (exposure in April-June 2021)

Indices	Points of sampling			
	ChEZ-1	ChEZ-2	ChEZ-3	ChEZ-4
Total absorbed dose rate ( <sup>137</sup> Cs+ <sup>90</sup> Sr), µGy/h	3.7	22.2	61.6	84.0
Stabilization coefficient (S)	0.213 ± 0.025 <sup>a</sup>	0.373 ± 0.050 <sup>c</sup>	0.318 ± 0.038 <sup>b</sup>	0.226 ± 0.072 <sup>a</sup>
Mineralization coefficient (k)	0.0035 ± 0.0017 <sup>a</sup>	0.0074 ± 0.0017 <sup>c</sup>	0.0097 ± 0.0040 <sup>b</sup>	0.0033 ± 0.0012 <sup>a</sup>
Reduced weight of green tea, %	66.3 ± 2.1 <sup>a</sup>	52.8 ± 4.2 <sup>b</sup>	57.4 ± 3.2 <sup>c</sup>	65.2 ± 6.1 <sup>a</sup>
Reduced weight of rooibos tea, %	14.8 ± 5.9 <sup>a</sup>	17.1 ± 1.9 <sup>a</sup>	21.8 ± 4.8 <sup>b</sup>	13.7 ± 3.7 <sup>a</sup>

Note. Letters a, b, c, and d indicate statistically significance at p ≤ 0.05. Each coefficient should be compared separately.

$\pm 0.034$  and  $0.0259 \pm 0.0156$ , and under the highest activity –  $0.428 \pm 0.044$  and  $0.0166 \pm 0.0022$ , respectively. While analyzing the obtained results for the rate of tea bag decomposition on Range No. 1, we did not find any significant difference in the variants, but the lowest index was noted for the lowest dose of RC.

As for the decomposition of a more stable substrate – rooibos, noteworthy is a significant increase in the intensity of vegetative material decomposition in points Narodychi-2 and Narodychi-3 compared to the point, characterized by the lowest RC level.

The coefficient of vegetative material mineralization on Range No. 2 got higher with an increase in RC in ChEZ 1, ChEZ 2, and ChEZ 3 (0.0035; 0.0074 and 0.0097, respectively), but in the area with the highest indices of ionizing radiation the coefficient decreased down to 0.0033 (Table 4). The rate of green tea decomposition was high and substantially comparable to the values obtained for Narodychi-3 on Range No. 1. The intensity of rooibos decomposition was somewhat lower. No statistical difference between the variants was found, but the lowest intensity of rooibos decomposition was observed at the highest level of soil RC.

The results of evaluating the indices under the second layout of the vegetative material on both ranges are

considerably confirmed by the data, obtained before. For instance, the increase in the mineralization coefficient and rooibos decomposition was noted for Range No. 1 in the point with the highest level of soil contamination (Table 5).

As for the range, located in the ChNPP exclusion zone (Table 6) there was a noteworthy tendency towards the increase in the mineralization coefficient (k) under the increase in the ionizing radiation dose from points ChEZ 1 to ChEZ 3. A place of the highest radiation level was characterized by a decrease in the index. Similar to the study of the first layout of vegetative material into soil, we noted a gradual increase in the intensity of tea decomposition in the first three points (ChEZ 1, ChEZ 2 and ChEZ 3) and some decrease in the indices for the highest RC level (ChEZ.4).

While determining the total microbial biomass of soil, some changes in indices were also noted depending on the level of contamination with radionuclides (Table 7). For instance, low levels of RC promoted the activation of the development of microorganisms. Within Range No. 1 the accumulation of the microbial biomass was the lowest under weak contamination (Narodychi 1) and the highest – under increased contamination (Narodychi 3). Analysis of soil in Range

**Table 5.** The change in the TBI indices depending on the level of contamination with radionuclides on Range No. 1 (exposure in July-September 2021)

Indices	Points of sampling		
	Narodychi-1	Narodychi-2	Narodychi-3
Total absorbed dose rate ( $^{137}\text{Cs}+^{90}\text{Sr}$ ), $\mu\text{Gy/h}$	0.20	1.00	1.57
Stabilization coefficient (S)	$0.215 \pm 0.028^a$	$0.197 \pm 0.014^a$	$0.208 \pm 0.020^a$
Mineralization coefficient (k)	$0.0094 \pm 0.0018^a$	$0.0091 \pm 0.0015^a$	$0.0149 \pm 0.0019^b$
Reduced weight of green tea, %	$66.1 \pm 2.4^a$	$67.7 \pm 1.2^a$	$66.7 \pm 1.7^a$
Reduced weight of rooibos tea, %	$25.3 \pm 3.1^a$	$25.5 \pm 3.0^a$	$32.9 \pm 2.3^b$

Note. Letters a, b, c, and d indicate statistical significance at  $p \leq 0.05$ . Each coefficient should be compared separately.

**Table 6.** The change in the TBI indices depending on the level of contamination with radionuclides on Range No. 2 (exposure in July-September 2021)

Indices	Points of sampling			
	ChEZ-1	ChEZ-2	ChEZ-3	ChEZ-4
Total absorbed dose rate ( $^{137}\text{Cs}+^{90}\text{Sr}$ ), $\mu\text{Gy/h}$	3.7	22.2	61.6	84.0
Stabilization coefficient (S)	$0.153 \pm 0.07^a$	$0.099 \pm 0.03^{a,b}$	$0.096 \pm 0.03^b$	$0.127 \pm 0.04^{a,b}$
Mineralization coefficient (k)	$0.0046 \pm 0.002^a$	$0.0044 \pm 0.001^a$	$0.0067 \pm 0.002^b$	$0.0052 \pm 0.001^{a,b}$
Reduced weight of green tea, %	$71.3 \pm 5.9^a$	$75.9 \pm 2.2^{a,b}$	$76.1 \pm 2.5^b$	$73.5 \pm 3.1^{a,b}$
Reduced weight of rooibos tea, %	$15.3 \pm 4.7^a$	$16.4 \pm 3.9^a$	$22.4 \pm 4.6^b$	$17.8 \pm 3.4^{a,b}$

Note. Letters a, b, c, and d indicate statistical significance at  $p \leq 0.05$ . Each coefficient should be compared separately.

No. 2 demonstrated much lower indices, especially in the point of the highest contamination.

The determination of the number of micromycetes in the investigated soil samples also demonstrated similar changes in indices depending on RC level (**Table 8**). For instance, the number of fungi in the soil of Range No. 1, as a rule, got higher with an increase in the contamination level (the exception is found in the study results for specific periods of sampling, for instance, in April 2021). However, in all the periods of the study, the lowest number of micromycetes among the investigated variants was noted in the sod-podzolic soil of Range No. 2. Yet the number of microscopic fungi was several times lower than the corresponding index for the soil of Range No. 1 depending on the places of sampling.

The feature of development depending on levels of RC noted for micromycetes was also remarkable for

cellulose-decomposing bacteria, but their number was very low (**Table 9**). In early spring and autumn, on Range No. 2 these bacteria were not found by traditional microbiological methods at all, which may demonstrate their insignificant involvement in the processes of decomposing vegetative residues under the investigated conditions.

While investigating the number of microorganisms-ammonifiers, it was found that the development of this group of soil microbiota representatives was activated along with the increase in RC level on Range No. 1 and at the same time, its development was inhibited in sod-podzolic soil of Range No. 2, especially in the place of the highest contamination level (**Table 10**). Thus, the peptolytic mode of organic residue decomposition (ammonification) was generally in agreement with the specificities of the course of the saccharolytic mode

**Table 7.** The total microbial biomass of the soil depending on the level of contamination with radionuclides, mg/kg of soil

Points of sampling	Periods of conducting analyses		
	I	II	III
<i>Range No. 1</i>			
Narodychi-1	not found	1575.9 ± 232.1	908.7 ± 5.3
Narodychi-2	not found	1583.1 ± 83.5	932.2 ± 9.3
Narodychi-3	not found	3806.2 ± 214.6	2190.5 ± 88.7
<i>Range No. 2</i>			
ChEZ-1	318.5 ± 35.9	546.3 ± 8.7	409.9 ± 15.5
ChEZ-2	430.0 ± 11.8	793.7 ± 17.9	618.4 ± 21.4
ChEZ-3	478.8 ± 15.5	947.4 ± 1.2	757.9 ± 17.5
ChEZ-4	200.9 ± 9.8	268.3 ± 12.6	217.4 ± 18.8

Note: Hereinafter: I – April 2021, II – July 2021, III – September 2021.

**Table 8.** The dynamics of the development of micromycetes depending on the level of contamination with radionuclides, thousand CFU/g of dry soil

Points of sampling	Periods of conducting analyses		
	I	II	III
<i>Range No. 1</i>			
Narodychi-1	120.0 ± 0.1	140,8 ± 15,7	38,3 ± 2,5
Narodychi-2	33.3 ± 0.1	190,8 ± 12,5	107,9 ± 9,1
Narodychi-3	433.0 ± 0.3	218,4 ± 8,9	90,2 ± 7,3
<i>Range No. 2</i>			
ChEZ-1	23.8 ± 4.1	48.9 ± 8.1	44.6 ± 2.4
ChEZ-2	36.5 ± 6.1	74.3 ± 13.5	37.2 ± 3.1
ChEZ-3	28.9 ± 4.5	100.5 ± 17.1	40.3 ± 4.1
ChEZ-4	15.2 ± 1.2	42.1 ± 8.0	29.3 ± 2.1

**Table 9.** The number of cellulose-decomposing bacteria depending on the level of contamination with radionuclides, thousand/g of dry soil

Points of sampling	Periods of conducting analyses		
	I	II	III
<i>Range No. 1</i>			
Narodychi-1	0.459	21.6	5.1
Narodychi-2	0.450	23.7	8.4
Narodychi-3	95.00	175.5	36.3
<i>Range No. 2</i>			
ChEZ-1	—*	23.7	—*
ChEZ-2	—*	47.4	—*
ChEZ-3	—*	48.6	—*
ChEZ-4	—*	17.7	—*

Note: \* – no bacteria found.

**Table 10.** The dynamics of the number of ammonifiers depending on the level of contamination with radionuclides, million CFU/g of dry soil

Points of sampling	Periods of conducting analyses		
	I	II	III
<i>Range No. 1</i>			
Narodychi-1	2.367 ± 0.381	17.123 ± 0.241	3.028 ± 0.244
Narodychi-2	6.950 ± 0.450	23.673 ± 0.232	4.032 ± 0.292
Narodychi-3	3.800 ± 0.195	41.340 ± 3.470	19.473 ± 0.111
<i>Range No. 2</i>			
ChEZ-1	0.650 ± 0.037	1.371 ± 0.094	0.076 ± 0.007
ChEZ-2	0.378 ± 0.018	1.988 ± 0.113	0.077 ± 0.005
ChEZ-3	0.474 ± 0.032	1.764 ± 0.104	0.074 ± 0.005
ChEZ-4	0.392 ± 0.019	1.139 ± 0.112	0.063 ± 0.004

(the development of such biodecomposers as micro-mycetes, first and foremost).

## DISCUSSION

The accumulation of microorganisms in soil has a decisive significance for the support of the functions of the aboveground ecosystems due to their role in the circulation, maintenance, and release of the main nutrients (McKenney et al, 2018). The decomposition of the vegetative plant residuals is a key process, determining the rate of biota performance in the ecosystem (Singh et al, 2017). Therefore, the ability to decompose cellulose is considered one of the most important indices of the total activity of soil microorganisms. The intensity of cellulose decomposition by microorganisms in soil depends on many ecologic factors (humid-

ity rate, temperature, acidity, etc.). The accumulation of microorganisms is also a sensitive indicator of environmental stress and reflects even small changes in the geochemical composition of their environment due to anthropogenic activity (Bano et al, 2018; Guillot et al, 2019; Hallsworth, 2019; Xiao et al, 2019). So, the ionizing radiation may also have some (not completely determined yet) impact on the activity of soil microorganisms (Kalashnikova et al, 1996; Romanovskaya et al, 1996; McNamara et al, 2003; Ragon et al, 2011; Chapon et al., 2012; Gu et al., 2014; Mousseau et al, 2014; Bonzom et al, 2016; Hoyos-Hernandez et al, 2019; Ogwu et al, 2019; Ihara et al, 2021).

The results of our research demonstrate the stimulating effect of low RC doses (Range No. 1) on the development and functioning of microorganisms, which

are cellulose decomposers (for example, the number of micromycetes increases by 1.6–3.6 times at the Narydychi 3 point compared to the indicators of the Narydychi 1 point). Under high RC doses (Range No. 2), the investigated indices decreased considerably (by an average of 10 times).

Certainly, such comparison of the obtained indices has its degree of conditionality, since the soils of both ranges can be compared only under complete coincidence of all soil and climatic parameters. We believe that though this comparison is conditional, it is still possible since the landscape of both ranges is flat, the moisture content in the samples was practically on the same level in all the periods of the study, the agrochemical indices were not contrastive. The ranges differ by their history. Though the soil on both ranges is sod-podzolic, yet in the first range it used to be cultivated and served as an agricultural field prior to the Chernobyl catastrophe. The sod podzolic soil in the ChNPP exclusion zone (Range No. 2) is in the forest, and there was a fire in the area with the highest level of radionuclides contamination in 2020 (see Figure 1, *b*, sampling point 4). Despite the above-mentioned differences between both experimental Ranges, we consider that one of the important parameters that allows us to distinguish the characteristics of the studied soils is the level of radionuclide contamination since the indicators differ by one or two orders of magnitude.

When the indices of radiation absorbed dose rate are considered, the biological activity of soils depends on the level of radionuclides contamination. It was demonstrated by both methods, used by us (both the TBI-index calculations and the determination of microbial biomass). These indices are in close correlation with the number of microorganisms, which are organic matter decomposers. The specificities in the development of microorganisms that are representatives of both saccharolytic and peptolytic modes of plant residuals biodecomposition are similar: their number increased under a relatively low increase in the radiation absorbed dose rate within Range No. 1 (the number of micromycetes increased by 1.6–3.6 times, cellulolytic bacteria by an average of 10 times and ammonifiers by 2.4–6.3 times) and was low in the soil of Range No. 2 (cellulolytic bacteria were not detected at all during certain periods of research, and the number of ammonifiers was 17–40 times less than the indicators of Range No 1). The lowest indices of the microorganisms number were remarkable for the pyrogenically transformed area in the ChNPP exclusion zone. Judging by our results, the

conclusion may be made that relatively low doses of ionizing radiation do not inhibit the development of microbiota in soil. It is confirmed to some degree by the publication of Bonzom et al (2016) who studied the intensity of forest floor decomposition in the ChNPP exclusion zone. According to their results, the mass of the forest floor was mainly lost with the increase in the intensity of the ambient dose rate of  $\gamma$ -radiation from 0.22 to 29  $\mu\text{Gy/h}$ . The authors came to the conclusion that the radioactive contamination of forest ecosystems for more than two decades did not necessarily have a negative effect on organic matter decomposition. Our results also indicate increasing of percentage of rooibos tea reduced weight with increasing radionuclide contamination for both Ranges (except point ChEZ-4, but this territory was pyrogenically transformed). Also we can compare ranges in radiation levels in our study and that of Bonzom et al. (2016). The sites selected by Bonzom et al. (2016) differed between 0.22 to 29  $\mu\text{Gy/h}$ , compared to our study sites ranging from 0.127 to 34.8  $\mu\text{Sv/h}$  (if we consider only  $\gamma$ -radiation dose rate we can compare Gy and Sv). Chapon et al. (2012), using both molecular- and culture-based approaches, demonstrated that in the radionuclides contaminated soil with  $^{137}\text{Cs}$  activity concentration within the range from 61 to 750 Bq/g did not lead to significant changes of bacterial diversity which was similar to that observed in control points of soil with significantly lower  $^{137}\text{Cs}$  activity concentration from 0.35 to 1.5 Bq/g, 25 years since the accident which may show the restoration of bacterial community.

However, studies by Mousseau et al (2014) demonstrated a decrease in the rate of forest floor decomposition by microorganisms in response to the increase in the radioactivity level, which resulted in enlarging the thickness of forest floor layer with an increase in the radiation dose rate for two sites among the most contaminated. This indicates a decrease in the activity of soil microbiota. It was also confirmed by the conclusions of Theodorakopoulos et al (2017), who conducted the investigation of the development of prokaryotes under different radioactivity levels and demonstrated that the total absorbed dose rate by the cell and decrease the organic matter content of the soil were the main impact factors which had the effect of reducing the diversity of prokaryotic communities.

At first glance, obtaining somewhat contradictory results to those of the above-mentioned authors can perhaps be explained both by the received radiation dose and by the different composition of radionuclides

in the soils. In addition, the different composition of the dead mass entering the soils may be important (due to the different structure and species composition of plant communities in the places of analysis), since the quality of plant remains is a powerful factor influencing the formation of microbial communities (Almagro et al, 2021).

In our study, noteworthy were extremely low numbers of cellulose-decomposing bacteria, especially compared to the number of micromycetes. Taking this fact into consideration, the conclusion can be made about the dominant role of fungi in the processes of cellulose biodecomposition in the soil contaminated with radionuclides. A similar effect was observed by Ogwu et al. (2019) while conducting the studies under targeted  $\gamma$ -radiation of a sandy loam soil. The authors assumed that the more active development of fungi and algae on the background of a decrease in the intensity of bacterial reproduction could be explained by the removal of competition from the ecologic niche.

The determination of the number of ammonifiers – the agents of the peptolytic mode of organic matter biodecomposition in soil – mainly demonstrated the course of development, similar to that of representatives of the saccharolytic mode, depending on the RC level. For instance, in the soil of Range No. 1, the number of these bacteria is rather high and increases with a higher dose of ionizing radiation. In the soil of Range No. 2, the number of ammonifiers is one-two orders lower than the indices of Range No. 1 which may demonstrate a negative effect of high RC levels on their development.

A destructive effect of high RC levels on the development of bacteria was noted in the studies, conducted soon after the accident. According to the data of Romanovska et al. (1998), the diversity of the cultivated bacteria, isolated in the 10-km zone around the ChNPP was two orders lower than that from the control non-contaminated areas. Similarly, the diversity of soil-borne bacterial communities was poorer in the samples from the areas of Fukushima with the highest RC levels (Ihara et al, 2021).

Theodorakopoulos et al (2017) predicted that chronic exposure with low doses of ionizing radiation may selectively affect the development of bacteria resistant to ionizing radiation in soils. As over thirty years have passed since the accident on the ChNPP, it would be quite expectable not to find any difference in the number of bacteria depending on the RC gradient in the soil of Range No. 1. The results obtained confirm these assumptions and even demonstrate the increase

in the total microbial biomass from  $1575,9 \pm 232,1$  to  $3806,2 \pm 214,6$  mg/kg of soil (Table 7). Another situation was observed for microbial development under high exposure doses. In the soil of Range No. 2, the number of representatives of the investigated groups of bacteria was one-two orders lower than the corresponding indices of Range No. 1. Therefore, our research shows that a high level of soil RC affects the development of the studied groups of microorganisms not only in the first years after accidental exposure, but also over a rather long period of time. During certain sampling periods, we did not manage to detect the development of cellulose-destroying bacteria in the soil of Range No. 2 at all. The number of ammonifiers was also one or two orders of magnitude lower compared to the parameters of the Range No. 1 soil.

Compared to the cellulose-decomposing bacteria, the fungi are not so sensitive to the negative effect of the soil RC. The intense development of micromycetes in the radionuclides contaminated soils was already noted by Zhdanova et al (1991), and Tugay et al (2005). Malo and Dadachova (2019) reported that some strains of micromycetes (genera *Cladosporium* and *Penicillium*) were capable of surviving under a high level (up to 100–50 Gy/sample) of ionizing radiation due to the accident in the ChNPP, using melanin synthesis as a radioprotector. But there are also dissenting statements. For instance, Panahova (2009) demonstrated on the sample of gray-brown soil of Absheron (Azerbaijan) that microscopic fungi were the most  $\gamma$ -radiation sensitive representatives of soil microbiota. However, it may be incorrect to compare the results of studies of the abovementioned authors since some of them were obtained in the ChNPP zone with constant selective stress of ionizing radiation, while others (Panahova, 2009) – under targeted single-time radiation. After all, the total doses absorbed by groups of microorganisms are probably more significant compared to the effect of instantaneous acute  $\gamma$ -radiation.

The results of our study confirmed a relative resistance of fungi to the ionizing radiation, but their development also depended on the gradient of soil radionuclides contamination.

Summing up, ionizing radiation is potentially lethal for microorganisms since the exposure energy may be sufficient to induce breaks in DNA strands (Ravanat, Douki, 2016; Song, Kuai, 2017). However, most microorganisms code normal enzymatic mechanisms of DNA restoration, due to which a large part of the damage is repairable (Jung et al, 2017). There were also re-

ports about some potential mechanisms of microbial resistance to radiation which turn on the detoxication systems of reactive oxygen intermediaries and enzymatic antioxidant processes (Pavlopoulou et al, 2016; Jung et al, 2017). The dose, under which it occurs for each specific species, is very variable (Ghosal et al, 2005), so theoretically, the survival of microorganisms and the formation of specific communities in soil, for instance, may depend on the gradient of RC. This is practically confirmed by the results of our study. On the other hand, in addition to the impact of radiation on the biological properties of soil, there is a known effect of this factor on the changes in physical and chemical characteristics of soil which may affect the development of microbiota. This point was substantiated in the publication of McNamara et al (2003): the radiation may affect both cellular physiology and bioavailability of growth substrates, i.e. the donors of electrons, acceptors, and possibly nutrients. It was also confirmed by other investigations. For instance, it was demonstrated that the ionizing radiation destroyed natural organic substances in soils which resulted in the increase in the content of soluble organic carbon therein (Bank et al, 2008; Schaller et al, 2011). This radiolytic degradation of organic matter may enhance the bioavailability of organic carbon for microbial metabolism and thus impact both the development of microbiota and its functional activity. Theodorakopoulos et al (2017) determined that, first and foremost, the development of microorganisms is affected by the total intensity of the exposure dose, absorbed by the cell, compared to the effect on organic matter.

The general conclusion can be made as follows: radioactive contamination affects the development of separate ecological and trophic groups of microorganisms in soil and depends on its gradient. Moreover, it is not known whether radiation pollution selectively affects the development of microorganisms at the level of individual taxa. This requires additional research using molecular biological methods. These studies are planned to be conducted as soon as there is an opportunity to take soil samples in the ChNPP exclusion zone.

## CONCLUSIONS

Our study demonstrated the dependence of the development and functioning of microorganisms – the representatives of saccharolytic and peptolytic modes of plant residues biodecomposition on the level of ionizing radiation. The relatively low intensity of the absorbed dose in the soil of Range No. 1 (up to 1.6  $\mu\text{Gy/h}$ ) stimulated the development of micromycetes

(by 1.2–2.3 times), cellulose-decomposing bacteria (by 7.1–7.9 times), and ammonifying bacteria (by 1.8–6.3 times) and promoted the increase more than two-fold their biomass accumulation. High intensity of the absorbed doses rate in the sod podzolic soil of Range No. 2 (from 3.7 to 61.6 and especially 84.0  $\mu\text{Gy/h}$ ) had a negative effect on the indices under investigation: the biomass of microorganisms decreased by 5.4–10.1 times, the number of micromycetes – by 2.1–3.3 times, ammonifiers – by 10–250 times compared to the indicators of Range No 1.

Under all the investigated levels of radionuclide contamination of soil, microscopic fungi dominated in the community of cellulose-decomposing microorganisms, which may demonstrate the main role of eukaryotic hyphal microorganisms in the decomposition of vegetative material under these conditions.

**Conflict of interests.** The authors declare the absence of any conflicts of interests.

**Compliance with standards of working with animals.** All the experimental results, presented in this article, were obtained without the use of any animals.

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### Вплив радіоактивного забруднення ґрунтів на різноманітність популяції мікроорганізмів і перетворення органічних речовин

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**Мета.** Вивчити вплив різних рівнів радіоактивного забруднення на процес розкладання органічної речовини та розвиток популяції мікроорганізмів-деструкторів органічної речовини в дерново-підзолистому ґрунті. **Методи.** Гамма-спектрометрія для визначення відносної активності  $^{137}\text{Cs}$  та бета-спектрометрія для визначення відносної активності  $^{90}\text{Sr}$  з метою вибору діапазонів забруднення для досліджень; індекс чайного пакетика (ТВІ), стандартний всесвітньо прийнятий метод визначення швидкості розкладання органічних речовин; газова хроматографія для визначення впливу досліджуваних факторів на формування біомаси мікроорганізмів за допомогою потенціалу продукування  $\text{CO}_2$ ; класичні мікробіологічні методи за використання електронних середовищ для оцінки щільності популяції куль-

тивованих мікробів-деструкторів. **Результати.** Дослідження (з квітня по вересень 2021 року) включали два варіанта дерново-підзолистих ґрунтів з різними діапазонами радіоактивного забруднення: полігон № 1 Народицького району Житомирської області (с. Христинівка, 3 експериментальні майданчики – окультурений ґрунт) в зоні безумовного (обов'язкового) відселення після катастрофи на Чорнобильській АЕС (має градієнт потужності поглиненої дози, оцінений для ґрунтових мікроорганізмів, від 0,2 мкГр/год (у точці відбору зразків Народичі-1: 51,24076°N, 29,21497°E) до 1,57 мкГр/год (у точці відбору зразків Народичі-3: 51,23815°N, 29,22245°E)), розташований на закинутому у 1990-х роках після катастрофи сільськогосподарському полі та полігон № 2, розташований на заліснених ділянках, що безпосередньо межують з територією так званого Рудого лісу зони відчуження ЧАЕС (4 експериментальні майданчики – перші три майданчики – природні екосистеми, а 4-й – пірогенно трансформований після пожежі у 2020 р.) з градієнтом потужності поглиненої дози від 3,7 мкГр/год (у точці відбору зразків ЧЗВ-1: 51,38595°N, 30,03035°E) до 84,0 мкГр/год (у точці відбору зразків ЧЗВ-4: 51,38231°N, 30,03298°E). Продемонстровано залежність досліджуваних показників від градієнта забруднення ґрунту радіонуклідами за різниці у величинах потужностей поглинених доз іонізуючого випромінювання, сформованих радіонуклідами в ґрунті, понад 400 разів. На полігоні № 1 (на перелогових землях) зі збільшенням потужності дози опромінення від 0,2 до 1,57 мкГр/год спостерігали статистично достовірне підвищення коефіцієнта мінералізації та відсотка зменшення маси чаю ройбуш між найменш і найбільш забрудненими точками відбору), стимуляцію розвитку мікроміцетів (у 1,2–2,3 раза), целюлозолітичних бактерій (у 7,1–7,9 раза), амоніфікаторів (у 1,8–6,3 раза) у точках із підвищеним радіонуклідним забрудненням та збільшення мікробної біомаси в ґрунті більш ніж у 2 рази між найменш забрудненою та найбільш забрудненою точками відбору проб. На полігоні № 2 у зоні відчуження ЧАЕС, що характеризується низькими показниками родючості дерново-підзолистого ґрунту (вмістом гумусу від 1,2 ± 0,2 до 0,9 ± 0,1 %, обмінною кислотністю від 4,0 ± 0,1 до 5,0 ± 0,7), чисельність мікроміцетів та амоніфікувальних бактерій у ґрунті була на один-два порядки нижчою від показників полігону № 1. Мікроміцети переважали в угрупованнях мікроорганізмів, що розкладають целюлозу. Для перших трьох ділянок: ЧЗВ-1, ЧЗВ-2 та ЧЗВ-3 полігону № 2 зі збільшенням рівня радіонуклідного забруднення відмічено статистично достовірне збільшення коефіцієнта мінералізації та відсотка зменшення маси чаю ройбуш. **Висновки.** На перелогових землях зони безумовного (обов'язкового) відселення збільшення потужності поглиненої дози опромінення

в ґрунті на один порядок, від 0,2 до 1,57 мкГр/год, не пригнічує розвиток мікроорганізмів у ґрунті, а стимулює їхню активність та підвищує кількість. На дерново-підзолистих ґрунтах зони відчуження ЧАЕС помітна перевага розвитку мікроміцетів над бактеріальними целюлолітиками. Радіоактивне забруднення вплинуло на розвиток ґрунтових мікроорганізмів і біологічні процеси в ґрунтах не лише в перші роки після Чорнобильської катастрофи, що описано в літературі, але діє впродовж досить тривалого часу (понад тридцять років після аварії). Серед мікроорганізмів сахаролітичного шляху розкладання рослинних решток домінують мікроміцети.

**Ключові слова:** Чорнобильська АЕС, радіоактивне забруднення, мікроорганізми-деструктори рослинних решток, розкладання рослинного матеріалу.

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